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T R Chidambaram[a], A R Krishnan[a] & N K Agarwal[a]
[a] Vikram Sarabhai Space Centre, Trivandrum 695 022, India.
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Advances in Launch Vehicle Electronics in India

T R CHIDAMBARAM, A R KRISHNAN AND N K AGARWAL
Vikram Sarabhai Space Centre, Trivandrum 695 022, India.

Electronics forms an integral part of a launch vehicle. As vehicles advance in capacity and complexity so does electronics concurrently with other aerospace technologies. The paper first describes technological advances in Navigation, Guidance and Control (NGC) system, and Telemetry, Tracking and Command (TTC) system, the two basic functional blocks of launch vehicle electronics, in early 70s to meet the demands of India's first launch vehicle SLV-3. It, then, describes the advances that took place in onboard electronics in 80s, and 90s to meet the requirements of polar and geosynchronous missions, as well as from developmental to operational missions. The paper also indicates future technological trends in this area.

REALISING the importance of electronic systems in launch vehicles' performance, development in this field was initiated in Vikram Sarabhai Space Centre concurrently with the development in other fields of rocket technologies. Even though development and qualification testing of Rohini and Menaka Sounding Rockets saw development of electronic systems for telemetry, tracking and command, major development in launch vehicle electronics took place during 70s to meet complex functional requirements of India's first Satellite Launch Vehicle, SLV-3. This included sensors, signal conditioners, PCM packages, transmitter and antenna for telemetry system. Also tone range receiver, telecommand receiver, decoder were developed for tracking and command systems. In order to steer the vehicle through a predetermined trajectory and to initiate various flight events to inject the satellite in the desired orbit, autopilot electronics, vehicle attitude programmer, sequencer, pyro systems were required. As the ISRO's launch vehicles program entered from development to operational phase demand on close tolerance on position and orbital parameters also increased considerably. Increasing complexity of the vehicles demanded measurements of large number of parameters, with better accuracy and onboard processing of the data. This was made possible by continuous development efforts and matching advances in the onboard electronics. The paper describes advances in electronics systems during various phases of ISRO's launch vehicle program.

Based on the functional requirements the launch vehicle electronics is generally divided into two categories:

- Navigation, Guidance and Control (NGC) System: The function of this system is to steer the vehicle through a predetermined trajectory to place the satellite accurately in its desired orbit.
- Telemetry, Tracking and Command (TTC) System: Telemetry system enables the monitoring of health and performance of launch vehicle subsystem. Tracking data provides instantaneous position of the vehicle and the telecommand system enables destruction in case of range safety violation.

NAVIGATION, GUIDANCE AND CONTROL SYSTEM

Navigation Guidance and Control system (NGC) is the brain of a satellite launch vehicle and it enables the launch vehicle to deliver the payload at the intended orbit. Modern NGC system is realised using sophisticated computer, electronics and fault tolerant software. The major components of the NGC systems are 1) Navigation System, 2) On Board Computers, 3) Control Electronics & Power Plants, and 4) Software for NGC and sequencing.

NGC system can be classified into (1) Preprogrammed simpler open loop guidance system and (2) Sophisticated highly accurate closed loop guidance system.

Open Loop and Closed Loop Guidance

In the open loop guidance scheme the vehicle trajectory is stored as pitch and yaw command profile. The system uses simple Attitude Reference System (ARS), Auto Pilot and Control Power Plant

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Interface. Open loop system is simple because no complex on board computations are required. Stored profile and the vehicles instantaneous state vectors are compared and the control power plants are commanded such that the vehicle takes the programmed trajectory. Early, in seventies, launch vehicles of Indian space program used open loop guidance scheme. Open loop guidance system suffers from relatively poor accuracy because the stored program can not take into account variations in performance of the propulsion systems.

Missions which require high accuracy use the closed loop guidance system. It is more accurate and complex. Variations in propulsion systems are taken into account and the vehicle is steered in an optimum path to achieve the end point using minimum energy. Also it is possible to take additional constraint with respect to the impact of spent stage and controlled heat flux limits on the satellites/electronic systems.

Closed loop systems require complex hardware and software. First of all a sophisticated Inertial Navigation System (INS) is required in place of ARS. Powerful digital computers execute the navigation, guidance and control function. Navigation software computes the vehicle state vector, guidance software steers the vehicle in the optimum path to reach the end point and auto pilot software generates the control commands. Stage control power plants provide the necessary control to maneuver the vehicle in the desired trajectory.

Latest launch vehicles of Indian Space Organisation use the highly accurate, redundant, fault tolerant NGC system. Typical block diagram of the NGC system is given in Fig 1.

Inertial Navigation Systems

Inertial Navigation System(INS) measures the attitude rates, position, velocity and acceleration of the vehicle. The accuracy required for a launch vehicle is of the order of 0.01 deg in the range of 360^{0} attitude, 15 m/sec velocity with a resolution of 0.1m/sec., 100,000 km in position with a resolution of one km, 15 to 18g in acceleration with resolution of micro g. This calls for highly accurate sensors and versatile navigation software. INS systems are implemented using gyros, either Rate Integrating type (RIG) or Dry Tuned Gyros (DTG) and pendulous servo accelerometers. Based on the method of mounting sensors , the INS is realised as platform based or strap down system.

Early launch vehicles of Indian Space Organisation used stabilised platform based INS (SPINS) with floated Rate Integrating Gyros (RIG) and servo accelerometers mounted in gimbals. Since the gimbals isolate the vehicle rotations, the sensors used in SPINS do not require large dynamic range and they are not subjected to the harsh environment of the vehicle. Since SPINS provides only attitude and acceleration information, separate three axis rate sensors are required to measure the vehicle rate for controlling the launch vehicle. SPINS is more complex in hardware but provide direct outputs with simpler software.

To achieve high reliability with minimum hardware Redundant Strapped down Inertial Navigation Systems (RESINS) are used in new satellite launch vehicle programs. In the strapped down version, Dry Tuned Gyro (DTG) and servo accelerometers are used to sense the vehicle rate and acceleration. Navigation software for strap down system should transform the body co-ordinates to inertial co-ordinates at much faster rate compare to a platform system. More complex software with quatronion transformations require faster computers.

Guidance software generates the steering commands for the launch vehicle to obtain its end conditions in an optimum way. Many algorithms like, velocity to be gained, flat earth guidance scheme and explicit guidance schemes are used. New launch vehicle use Digital Auto Pilot (DAP) software for controlling the launch vehicle. DAP is versatile and easy to reconfigure and retune the parameters of vehicle. This enables the system design faster and accommodate the changes of vehicle parameters without much redesign of electronic hardware.

Electronics for NGC Systems

NGC system consists of large number of electronic circuits. To start with Inertial Navigation System requires precision torque rebalance loop, highly stable voltage to frequency conversion, low drift servo electronics, accurate temperature controller, stable excitation and demodulator circuits, high current DC-DC converters etc. Navigation, guidance and control software are executed in high speed real time computers. Sequencing electronics interfaces are based on redundant systems using fault tolerant decoders and relays to interface pyro elements of the vehicle. High Power Control electronics interfaces with pulse width modulated power amplifiers used in control power plants.

First generation launch vehicle of Indian Space Organisation used open loop guidance scheme with preprogrammed vehicle attitude programmer with sequencer for vehicle staging events at programmed

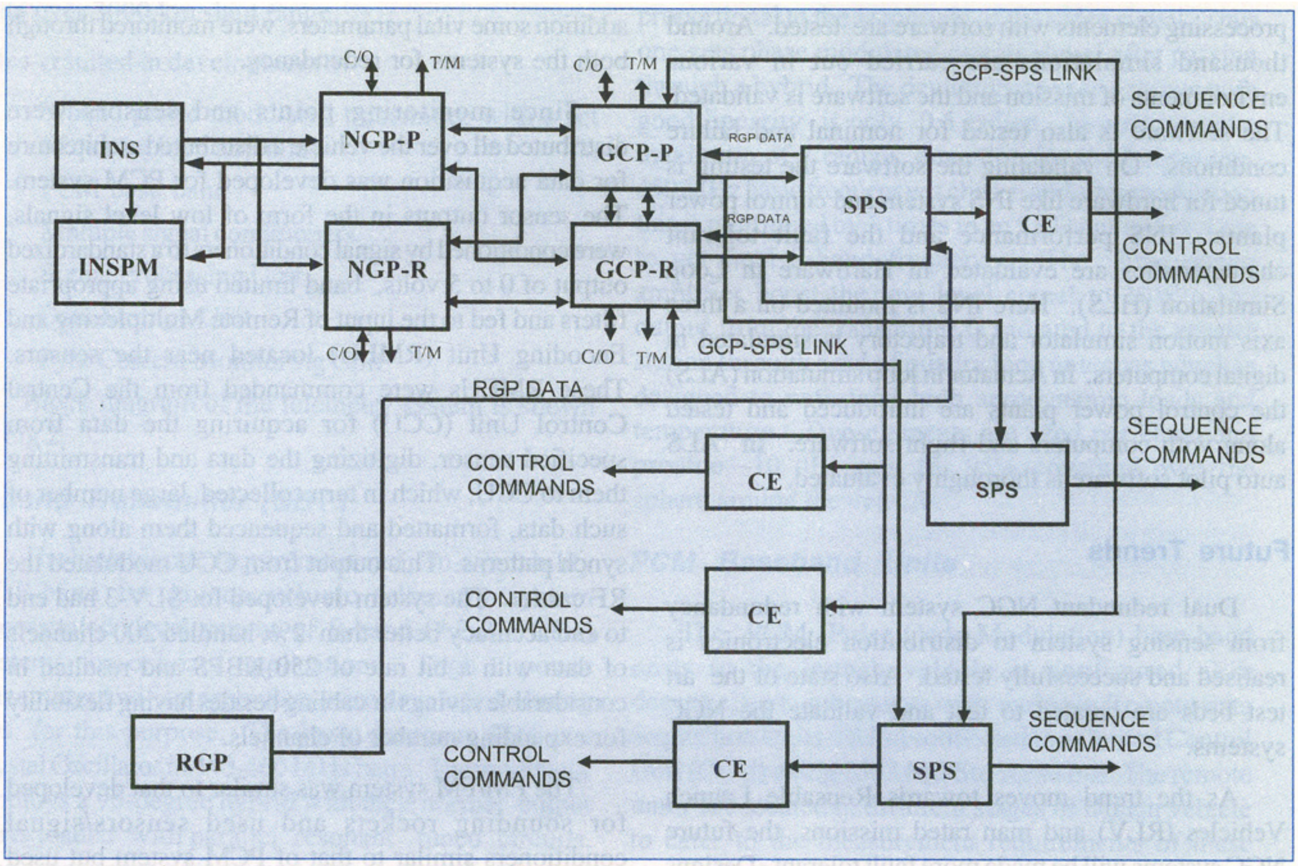

Fig 1 NGC system configuration

time. Auto pilot was realised using analog amplifiers and fixed filters switched at preprogrammed intervals. The electronics were relatively simpler but having deficiencies in terms of robustness, programmability, reliability and adaptability to future generation vehicles.

Over the years, Indian Space Research Organisation has developed versatile, mission independent, programmable, reliable NGC system with fault tolerant features. Modern missions of Space Organisation use scalable NGC system. Typical system consists of redundant strap down inertial navigation systems, microprocessor based redundant on board computers, stage processing electronics, smart control electronics interfaces. Redundancy is built into the system such that multiple failures can be tolerated and the NGC system will deliver the intended function without any degradation.

Present day launch vehicles have about half a dozen computers providing a two fold redundancy. These computers communicate with each other through Mil-Std 1553B links and have provision for fault detection and isolation. In contrast to the computer hardware, there is an invisible software - both system and application software. The application software involves, for example, compensation of sensor errors, precision computation of navigation parameters, implementation of guidance algorithm and the digital auto pilot. These software modules require fault tolerant features.

Simulation

Having realised sophisticated on board electronics hardware and software with fault tolerance, the challenge is to validate NGC for varying vehicle environments. It is really a difficult task to realise the test bed and validate the entire NGC system. This calls for the realisation simulation test beds with multiple computers and realtime operating software. Indian Space Research Organisation has developed simulation test beds for Autonomous simulation, on board computer simulation, Hardware in loop simulation and Actuator in loop simulation. In autonomous simulation thousands of runs are taken to validate the design algorithms and overall system design. This is done using standard digital computers and the design algorithms are coded in Fortran. Once the system design is validated the next phase starts with the testing of on board software and hardware. In onboard computer simulation, actual

processing elements with software are tested. Around thousand simulations are carried out in various environments of mission and the software is validated. The software is also tested for nominal and failure conditions. On validating the software the testing is tuned for hardware like INS system and control power plants. INS performance and the fault tolerant characteristics are evaluated in Hardware in Loop Simulation (HLS). Here INS is mounted on a three axis motion simulator and trajectory is simulated in digital computers. In Actuator in loop simulation (ALS) the control power plants are introduced and tested along with computers and flight software. In ALS auto pilot software is thoroughly evaluated.

Future Trends

Dual redundant NGC system with redundancy from sensing system to distribution electronics is realised and successfully tested. Also state of the art test beds are created to test and validate the NGC systems.

As the trend moves towards Reusable Launch Vehicles (RLV) and man rated missions, the future NGC systems will be made more fault tolerant. Designs are being taken up for triple modular redundancy with majority voting, introduction of fault tolerance in control power plants and cost effective miniaturisation etc. As part of an important goal of achieving self sufficiency progressive indigenisation efforts are taken up. Designs of digital, analog and mixed signal ASICS are carried out and they are being realised using indigenous electronic foundries.

TELEMETRY, TRACKING AND COMMAND SYSTEMS

Telemetry System

There is greater need, especially during the development flights, to monitor the performance of various subsystems of the launch vehicle. India's first launch vehicle, SLV-3, was made up of 250 subsystems. Monitoring detailed performance of these subsystems during the flight was of paramount importance and the telemetry system was designed to meet this requirement. Nearly 300 parameters involving pressure, acceleration, attitude, temperature, vibration, voltage input/output of various functional electronics and health parameters of various subsystems had to be telemetered in real time during the short period of flight. A combination of PCM/FM and FM/FM systems was employed for this purpose. The PCM system was meant for high accuracy measurements and the FM system was used for large bandwidth data. In addition some vital parameters, were monitored through both the systems for redundancy.

Since monitoring points and sensors were distributed all over the vehicle a distributed architecture for data acquisition was developed for PCM system. The sensor outputs in the form of low level signals, were conditioned by signal conditioners to a standardized output of 0 to 5 volts, band limited using appropriate filters and fed to the input of Remote Multiplexing and Encoding Unit (RMEU) located near the sensors. These RMEUs were commanded from the Central Control Unit (CCU) for acquiring the data from specified sensor, digitizing the data and transmitting them to CCU, which in turn collected, large number of such data, formatted and sequenced them along with synch patterns. This output from CCU modulated the RF carrier. The system developed for SLV-3 had end to end accuracy better than 2%, handled 200 channels of data with a bit rate of 250 KBPS and resulted in considerable savings in cabling besides having flexibility for expanding number of channels.

The FM/FM system was similar to that developed for sounding rockets and used sensors/signal conditioners similar to that of PCM system but used VCOs and mixer amplifiers in place of RMEUs and CCU. End to end accuracy was better than 5% and hence catered to large bandwidth data such as vibration. In addition the system also catered to the onboard requirement of tone ranging.

In view of the technology limitation in early 70s, VHF (215-260 MHz) transmitters with frequency modulation and 4W output power were developed for the above-mentioned telemetry systems. The output of the transmitter was fed to a set of spike antennas, which provide near omni directional radiation pattern. The spike antenna was selected because of its high power handling capability at P-band in vacuum. Telemetry system realized for SLV with P-band transmitter and spike antenna was having sufficient link margin for maximum slant range of 1500 km.

As the complexity of launch vehicles increased, there was requirement for measuring larger number of parameters, specially during development phase. For example, ASLV needed 900 parameters to be monitored. The telemetry links in P-band with its limited bandwidth could not meet this requirement with limited number of chains in the vehicle. Also, FM/FM system becomes unwieldy when large number of parameters are to be monitored. Besides, as mentioned above, such systems lack accuracy compared to PCM system. Consequently efforts in 1980s were directed towards development of a telemetry system which could transmit 1 MBPS PCM

data over 3000 km slant range.

This resulted in development of

- S-band phase modulated transmitter with a set of quadra loop antennas
- PCM base band
- Multiple signal conditioners.
- Signal Processing Unit
- Data Storage Unit
- Pyro Current Monitoring Unit

Block diagram of the telemetry system is shown in Fig 2.

S-band Transmitter (SBT)

The high bit rate requirement and non-availability of P-band for launch vehicle telemetry system necessitated development of S-band (2.2-2.3 GHz) systems for onboard applications. High power transmitter and transponders were developed during 80s for this purpose. The basic source in SBT is a crystal Oscillator in 440-460 MHz band. The modulator employs a 90-degree hybrid with their normal output ports loaded with parallel resonant tuned circuits. The capacitance of the tuned circuit is realized using varactor diode. The capacitance value of the tuned circuit is proportional to the amplitude of the PCM video signal and hence the phase of the carrier is also proportional to the amplitude of the video signal. Thus one gets phase modulated carrier signal after passing through a hybrid. The deviation one can achieve with good linearity is only 0.5 radian. In order to get a maximum of 2 radian deviation for the transmitter, 450 MHz basic frequency is chosen and after modulation this is multiplied by 5 times in an SRD multiplier stage to get final S-band frequency. The final power amplifier boost the low level signal to 10W. The output from the transmitter is radiated to the ground station through a set of quadra loop antennas which is designed to withstand high aerodynamic loads and temperature. Two elements are used per chain and provide –10 dBi gain for 95% coverage over the sphere around the vehicle.

PCM Baseband Units

The PCM (Pulse Code Modulation) base band units in the launch vehicle is configured as a decentralised subsystem with multiple Remote data acquisition Units (RU's) connected to a Central Control Unit (CCU) using 1553 Mil Std serial bus. The remote units are located in different stages of launch vehicle to cater to the measurement requirements of these stages. Each remote unit can accept 96 analog inputs and 32 digital inputs. The analog inputs are standardised to a range of 0-5 volts and each digital input has one bit resolution. Apart from these inputs the remote units

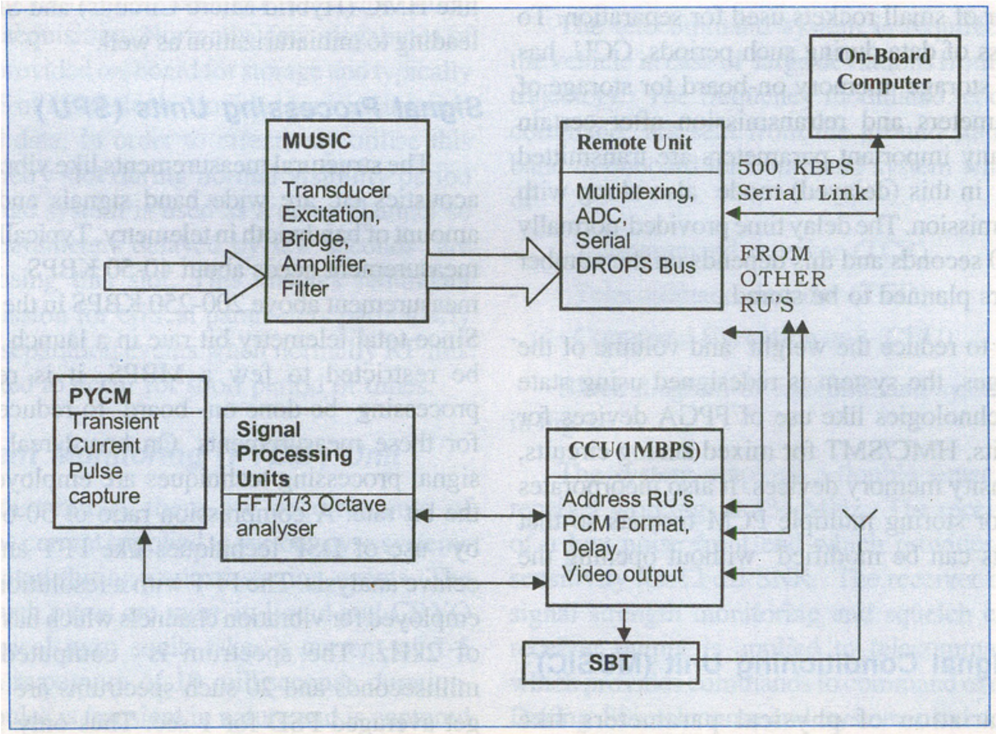

Fig 2 S-band PCM telemetry system

are also designed to communicate with microprocessor based systems like on-board computers for transfer of NGC related parameters. The dedicated serial links are custom designed and operate at 500 KBPS. The remote units collect data from on-board computers through the serial link during every minor cycle time of the processor (typically about 20 milliseconds). On-board computer transfers data to RU in a block mode with start and stop words at beginning and end of each data frame. The data word length is 8 bits. The data is transferred as a burst in few milliseconds in each minor cycle.

The remote units are connected to central control unit located near SBT. There are independent address and data serial bus links connecting CCU to each RU. 12 remote units can be connected to one CCU. CCU addresses each RU as per the PCM format stored in CCU.(IRIG compatible and typical format size is being 120 ′ 16) The CCU also has provision for storing multiple formats which can be changed by commands. The CCU provides band limited bi-phase video output which is the modulation input to SBT. The CCU also provides separate transformer coupled video data and clock output for use by checkout system directly without the need for RF transmission.

During flight it is possible that ground station could miss on-board data for few milliseconds to few seconds particularly when it is looking at the vehicle through flame of the solid propellant stage. This also happens during separation of stages due to firing of large number of small rockets used for separation. To avoid the loss of data during such periods, CCU has provision of storage memory on-board for storage of critical parameters and retransmission after certain period. Many important parameters are transmitted redundantly in this (delayed) mode also along with normal transmission. The delay time provided normally is about 5-10 seconds and this depends on the number of parameters planned to be stored .

In order to reduce the weight and volume of the PCM packages, the system is redesigned using state of the art technologies like use of FPGA devices for digital circuits, HMC/SMT for mixed analog circuits, and high density memory devices. It also incorporates E^2PROM for storing multiple PCM formats so that these formats can be modified without opening the packages.

Multiple Signal Conditioning Unit (MUSIC)

The variation of physical parameters like temperature, pressure, acceleration, strain etc are to be converted to PCM compatible electrical output of 0-5V for monitoring through telemetry. The bandwidth of each measurement is also to be limited to reduce aliasing error. Analog circuits called signal conditioning circuits in launch vehicle perform the above functions. Each parameter to be measured needs a particular signal conditioning circuit. Many such circuits are combined on to a single package called multiple signal conditioning (MUSIC) module. To reduce weight and volume and also to reduce number of packages on-board, typically MUSIC packages are designed to cater to 36, 48, 72 channels etc. depending upon the number of measurements needed in each stage.

The functions of signal conditioning unit are as follows:

(1) Transducer bridge and excitation

(2) Voltage Amplification (typical gain 1-1000)

(3) Low pass filtering as per required bandwidth (Typical BW of signal range from 6 Hz to 2 kHz)

Structural measurements like vibration, shock etc need larger bandwidth of 1500-2000 Hz and acoustic signal about 8 kHz. Apart from providing sufficient gain, the circuits should also provide high CMRR for reducing noise and high stability. Since measurement requirements in each launch vehicle are about 1000-2000, number of MUSIC packages needed are very large. Also these packages constitute large weight and consume more volume in EB. To reduce the weight and volume, advanced fabrication technologies like HMC (Hybrid Micro Circuits) and SMT are used leading to miniaturization as well.

Signal Processing Units (SPU)

The structural measurements like vibration, shock, acoustics etc are wide band signals and need large amount of bandwidth in telemetry. Typically a vibration measurement needs about 40-50 KBPS and acoustic measurement above 200-250 KBPS in the PCM chain. Since total telemetry bit rate in a launch vehicle is to be restricted to few a MBPS, it is required that processing be done on- board to reduce the bit rate for these measurements. On board real time digital signal processing techniques are employed to reduce the bit rate. A compression ratio of 50-60 is feasible by use of DSP techniques like FFT and one-third-octave analysis. The FFT with a resolution of 20 Hz is employed for vibration channels which has a bandwidth of 2kHz. The spectrum is computed every 50 milliseconds and 20 such spectrums are averaged to get averaged PSD for 1 sec. Thus only 100 samples are transmitted per second instead about 6 K samples needed for direct transmission. The acoustic signals

are analysed on-board as per one-third octave analysis, covering a frequency range of 25 Hz to 8 kHz. The analysis is carried out by implementation of digital IIR low pass and band pass filters. One spectrum is computed every 250 milliseconds and is transmitted to ground through PCM. . By use of on-board digital signal processing techniques it has been possible to monitor large number of vibration and acoustic measurements in a launch vehicle system during development flights. The real time digital processor system uses high speed DSP devices and the unit directly interfaces to on-board PCM system, through 1553 serial bus.

The shock measurement is a transient signal needed to be monitored only for a short period during ignition/ separation of stages. These are captured at predetermined time slots at a very high sampling rate (6000-7000 S/s) for 1-2 seconds and re transmitted through telemetry in between the events at a slower rate of typically 100-200 samples per second.

Data Storage Unit (DSU)

During certain period of the flight it is possible that launch vehicle is not visible to any of the ground stations for a few seconds to tens of seconds. In order to record important parameters during this period of non-visibility, data storage unit is employed on-board. At predetermined periods the critical parameters planned for storage are stored in the on-board memory. After the visibility is ensured, the data from the storage memory is transmitted to ground along with time of acquisition. Normally few megabytes of memory are provided on-board for storage and typically 50-100 KBPS of PCM slot is provided for transmission of the stored data. In order to effectively utilise this storage telemetry slot during normal visibility period the data storage system is used as a delay channel so that critical parameters delayed by few seconds are transmitted using this slot. This ensures redundant delay transmission for critical parameters particularly during stage separation events when normally RF link loss is expected to occur for short period of times.

Pyro Current Monitoring (PYCM) Unit

In launch vehicle, there are requirements of monitoring the current supplied to various pyro systems that are operated during various staging events. The number of such pyros are more in liquid and CRYO stages. A typical pyro squib takes a current of 1-5 Amp. for a maximum of 10 milliseconds duration. The current pulse is transient in nature and is captured for a few milliseconds only. The monitoring of such pyro currents need large bandwidth for a short duration and need sampling rate of 10-20 KS/sec for proper reconstruction. A unique system called on-board pyro current monitoring unit has been developed to capture the events of pyro current firing. It uses Hall effect sensors for converting current into a voltage pulse. The return of the pyro current line is looped through the sensor and it has no physical connection to it. Hence the monitoring scheme is totally isolated from pyro circuit which is mandatory for pyro circuit safety. The data from the Hall effect sensors are recorded on–board . The recording is initiated by sensing the start of the current pulse and data is stored on-board for about 40-50 milliseconds. The unit also provides for inhibition for next 200 milliseconds to avoid overwriting into the memory where the current pulse is stored. This is to avoid loss of data that could occur sometimes due to continuous current flowing through squibs because of shorting of squib leads during operation and also due to chattering of relay contacts which can be mistaken as current pulse. The current measurement that are displaced in time can be combined in the same Hall effect sensor resulting in optimum usage of sensors. The current pulse data is transmitted through the PCM encoder at a slower rate and it takes about 2-3 sec for retransmission. The PYCM unit has about 40 Hall effect sensors and monitors the firing of about 150 squibs and needs a transmission bit rate of 64-128 KBPS only. Thus a bit rate reduction of 100-200 times is achieved per channel.

Telecommand System

The telecommand system is required to destroy the vehicle in case of large deviations from its intended trajectory. The frequency modulated, coded destruct command are sent from the ground station in UHF band to onboard telecommand system which consists of

- Telecommand receiver (TCR)
- Telecommand decoder (TCD)
- Command Execution unit (CEU)

Block diagram of telecommand system is shown in Fig 3.

The system employs a double super heterodyne receiver working at 434 MHz. The receiver consists of a low noise front end which provides –110 dBm sensitivity for 12 dB SNR. The receiver incorporates signal strength monitoring and squelch circuit. The receiver output is applied to telecommand decoder which provides commands to command execution unit. During 80s telecommand system used tone digital techniques but later a digital telecommand system based on convolution coding was developed which has

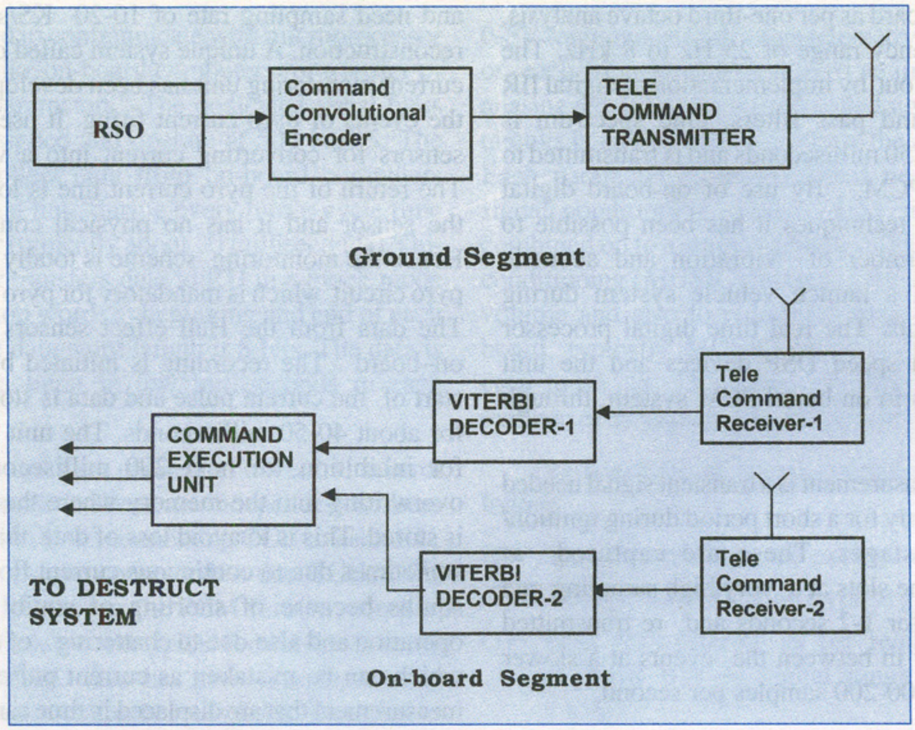

Fig 3 Telecommand system

better immunity to noise. Though the flight requirement is only for three commands the system developed with 8-bit length has a functional capability of providing upto 72 commands.

The Tele-command Decoder (TCD) works on convolutional coding and Viterbi decoding techniques. Mainly three commands are needed to be generated for destruct purposes in a launch vehicle. They are safe, arm, and destruct. However, one or two additional commands are also included for other operations like inhibition of certain stages like CRYO etc. The ground encoder generates safe, arm and destruct commands using hamming code(7,3). The encoded command is passed through a 1/2-convolution coder before transmitting through ground tele-command FSK/FM transmitter. Normally safe command is issued continuously from ground encoder. In case launch vehicle deviates from expected trajectory and need for destruction arises the safe command is removed, and then arm and destruct commands are given successively. In the on-board system the Tele-command decoder receives the video from the receiver and decodes the commands using Viterbi decoding technique. The convolutional coding and viterbi decoding ensure that very low possibility exists of wrong command being decoded (10^{-42}) and correct command not being decoded properly (10^{-35}).

Command Execution Units (CEU) located in different stages of the launch vehicle carry out the actual destruct function. The arm command initiates the power supply to command execution units. Upon receipt of destruct command from TCD, the required pyro relays are operated for supplying required voltage to operate destruct pyro squibs. The TCD operates in fully dual redundant mode with independent batteries for each chain. The command execution units receive outputs from both chains and can operate satisfactorily even with normal functioning of one TC chain.

Tracking System

The tracking system is required for obtaining real time trajectory data of the vehicle. It is mission critical because trajectory data is required for range safety purpose. Over the years, depending upon the requirement various tracking systems were developed and deployed for tracking rockets and launch vehicles.

During 60s skin mode tracking by COTAL radar in S-band was employed. It was used for sounding rockets and had a slant range of 80 km to 100 km. In order to meet tracking requirements of launch vehicles two types of tracking systems were developed in 70s.

1. Tone range and interferometer system
2. C-band transponder

Tone Range and Interferometer

The onboard tone range receiver at 543.46 MHz receives frequency modulated 100kHz and 4.5kHz ranging tones from Tone Range and Interferometer (TRIM) ground station. After amplification, down conversion and demodulation the tones are sent back to ground station by the onboard P-band transmitter along with FM/FM telemetry data. The phase shift between the outgoing and incoming tones provides slant range of the vehicle.

The interferometer provides angular information of the vehicle by measuring phase difference between two signals received by the antennas separated by 16 wave lengths. By using four antennas placed orthogonally elevation and azimuth angles can be derived from the phase differences between received signals. The tone range interferometer system provided tracking data upto a slant range of 1000km. Parallelly C-band transponder was developed for meeting higher tracking requirements of future launch vehicles.

C-band Transponder

The indigenously developed C-band transponder is being used to track launch vehicles since early 80s. With 400W peak output power, 1170 PRF and 1 microsec pulsewidth it can provide tracking data up to 3000 km in conjunction with the ground based radars operating in 5.4 to 5.9 GHz frequency range. The C-band transponder demanded wide range of technologies such as thyrister modulator, digital control circuits, microwave front end and high power C-band source. All these were to be integrated into a single low volume, low weight package. The signal transmitted from the ground radar is received by a set of loop antennas and is fed to the receiver portion via a circulator. The RF signal is down converted to 60 MHz IF in a mixer stage using DRO as local oscillator.

The pulse is detected and amplified and is used for pulsing the magnetron through a modulator. A miniaturized space qualified magnetron is used for realizing the transmitter. The transmitter output is fed to the antenna via a circulator. The onboard loop antenna provides a gain of –15 dBi for a coverage factor of 90%. Two identical chains are used for higher reliability.

S-band Range and Range Rate Transponder (SRRT)

For preliminary orbit determination (POD) of the payload, S-band range and range rate transponder was also developed and deployed during 80s. This unit, also called CW transponder, not only provides more accurate range data but also provides velocity of the vehicle till injection of the satellite in the orbit. The unit also provides additional telemetry chain. The SRRT works on the measurement of phase change which a set of tone signals undergo during propagation from ground station to the vehicle and back. The range rate is obtained from Doppler shift in the frequency. The SRRT provides vehicle range and range rate data to an accuracy of 10M and 0.1M/sec. respectively. The transponder consists of a phase lock receiver of –115 dBm sensitivity and a 10W transmitter phase modulated by tones and 1MBPS PCM telemetry data. The phase noise under all environmental condition is less than 0.15 radian. The other main features of the unit are:

- phase locks to and tracks the uplink frequency
- auxiliary transmitter for telemetry data in case phase lock circuit fails
- generates coherent drive for transmitter for down link at 240/221 of uplink frequency.

Future Trends

With the advances in the device technology in terms of density and speed, it is now possible to realize mission independent miniaturized TTC systems, which are ~~small in~~ size, less in weight, power efficient and capable of performing smart functions. A telemetry system which can transmit 2 MBPS PCM data with a 5W transmitter to a range of 1500 km, is under development. The special features of such a system are:

- Advanced PCM base band sub system with error correcting coding (concatenated coding scheme with random error correcting convolution inner code and a burst error correcting reed Solomon outer code) implemented on FPGA/ ASIC by using VHDL.
- Custom built MMIC based transmitter, QPSK modulator, Ga AS FET power amplifier and frequency programmability through RS 232 bus.
- Data acquisition units with software programmability for in-situ gain-bandwidth adjustment to take care of different type of transducers and mission to mission range/ response variations.
- Use of integrated transducers and amplifiers.
- Onboard real time spectral analysis with signal processing units for high frequency parameters like vibration and acoustic data.
- Onboard transient data capture for recording squib currents and shock events

- Data storage capability with delay and storage functions during non-visibility periods
- Use of sigma-delta ADC chips for high accuracy measurements
- High density analog signal conditioners employing HMC/SMT techniques.

For tracking of the vehicle a pulsed tracking C-band transponder which is compact and efficient is being realized by using 4 custom built chips and Ga AS FET power amplifier.

A novel method of realizing telecommand receiver and decoder as a single package using three chips is also being pursued. Jamming free Telecommand system by employing digital modulation and coding techniques is also under development.

CONCLUSION

With the advances in device technology in terms of functionality, density and speed it is now possible to realize launch vehicle electronic systems which are smart, power efficient and are small in size and weight. Also as the availability of devices to MIL-STD-883B and higher quality levels is becoming scarce the new designs are planned using industrial grade ICs with inhouse screening. Higher level of integration in the form of ASICS and extensive use of SMDs with package level of qualification and acceptance are planned for non mission critical applications like Telemetry Systems. Use of COTs technology and PEMs is also planned for such systems to reduce the cost. Electronic systems of India's future launch vehicle will have many such features.

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Authors

TR Chidambaram obtained his postgraduate degree in engineering from Madras University in 1973. He had joined VSSC in 1973 and currently holding Group Director posts for Computers and Digital Systems Group, and Mission Synthesis and Simulation Group. He had contributed in the development of Navigation Guidance and Control System of Launch Vehicles. Presently he is working on the development of advanced avionics system for GSLV as Project Director.

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AR Krishnan had his graduation in Electronics & Communication Engineering from University of Madras in June 1972. He joined VSSC on March 1973 and continuing to work in areas of Sounding Rocket Integration, PCM baseband system design, design of DSP based Signal Processing System. He is currently heading the Electronic Production Facility Division of Avionics Entity, VSSC which is responsible for realization of Avionics packages for Launch Vehicle requirements.

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NK Agarwal passed MSc Tech in Electronics in 1968 from Birla Institute of Technology and Science, Pilani. He joined Central Electronics Engineering Research Institute same year and worked there for three years on design and development of high gain Yagi antenna and booster amplifier for fringe area TV reception. Thereafter, he joined Vikram Sarabhai Space Centre at Trivandrum. Where he is still working as Group Head, RF Systems Group. He significantly contributed in the design and development of onboard antennas, RF modules for Launch Vehicle applications. He is also looking after EMC aspects of Launch Vehicles for the last 25 years. Published nearly 20 papers on EMI/EMC in various journals. Life member of Society of EMC Engineers (India).

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